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(54) Selective machining by dual wavelength laser

(57) A method of selectively machining a component such as a printed circuit board which comprises a first material 2 (copper) and a second material 3 (insulating substrate) comprises the steps of: using a single laser 1 having first and second emission wavelengths to selectively irradiate the component with a pulsed laser beam of the first wavelength at an energy fluence sufficient to cause ablation of the first material but insufficient to cause appreciable ablation of the second material; and selectively irradiating the component with a pulsed laser beam of the second wavelength at an energy fluence sufficient to cause ablation of at least the second material, whereby holes and slots may be cut in the component by simultaneous or successive irradiation by the two wavelengths. The apparatus for carrying out this method employs a laser 1 switchable between different wavelengths and a control means to coordinate the laser with the workpiece.

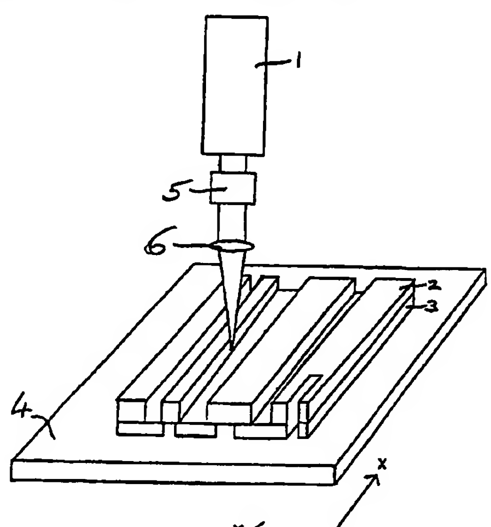

FIG. 1.

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

GB 2 286 787 A

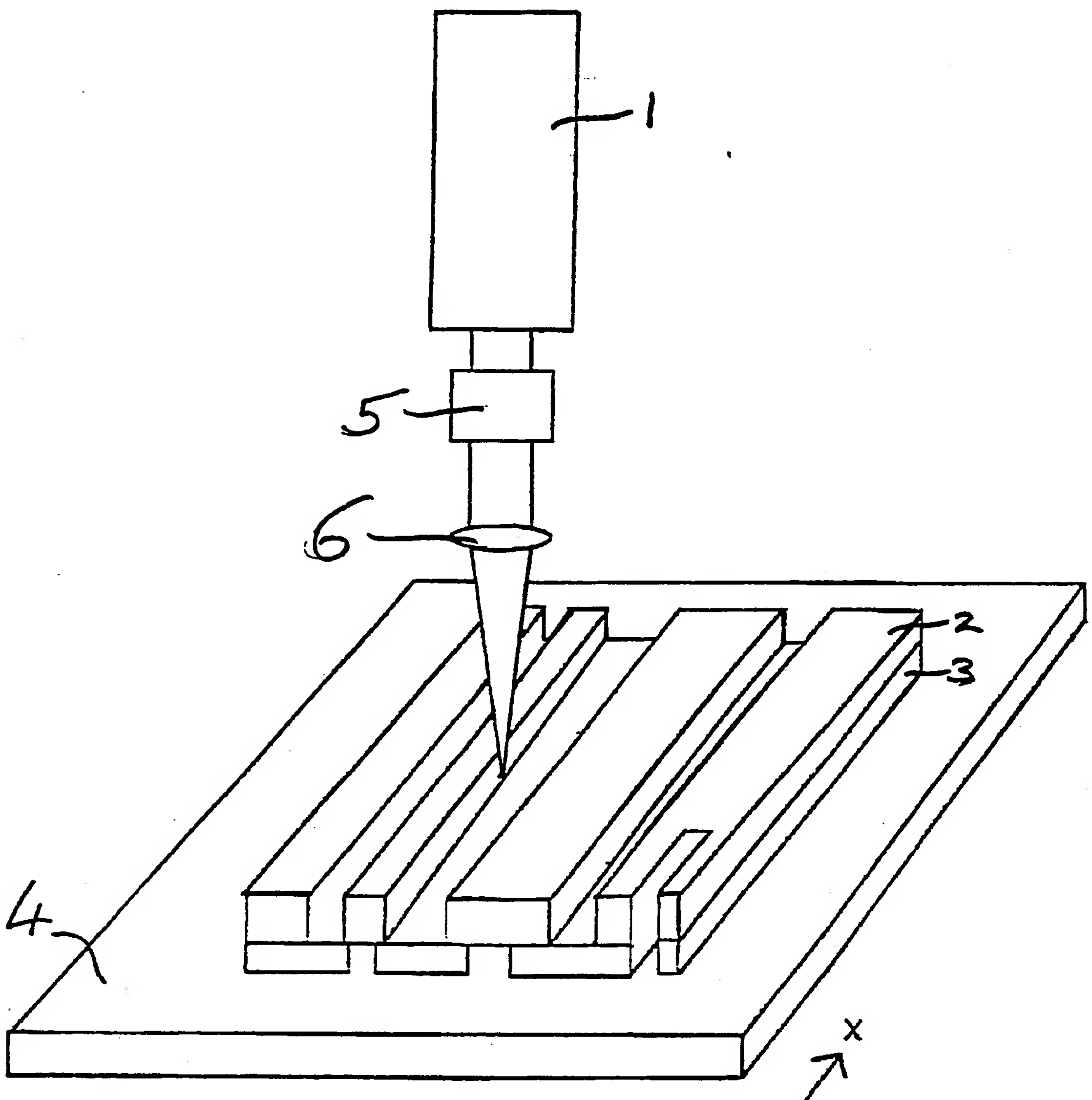

FIG. 1.

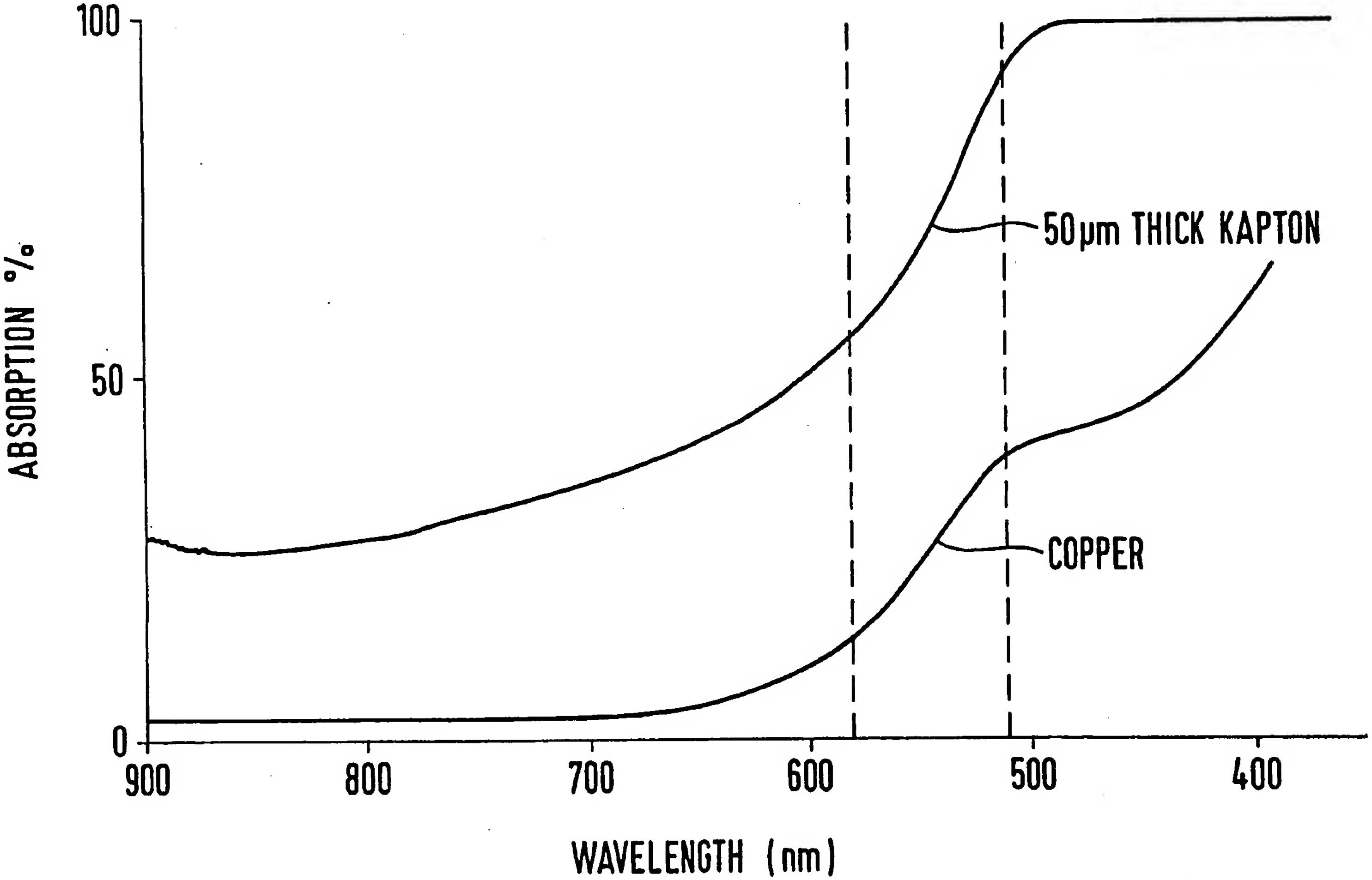
100
50
0
ABSORPTION %
900
800
700
600
500
400
WAVELENGTH (nm)
50μm THICK KAPTON
COPPER

Fig.2

SELECTIVE MACHINING BY LASER

This invention relates to a method and apparatus for selectively machining a component comprising a first material and a second material, for instance a circuit board comprising a layer of copper and an insulating substrate.

Printed circuit boards have conventionally been manufactured using photochemical etching (PCE) techniques to form the required pattern of tracks in a layer of copper on an insulating substrate. PCE involves the production of artwork which is then photographically reduced for high resolution. However, the reduction process can lead to scaling and other errors. Optical limitations of the imaging process mean that a given resolution can only be achieved over a finite area. PCE is only able to etch the metal layer and is not able to fabricate holes or cuts through the board. Also, only certain metals may be etched and the chemicals involved can be highly toxic.

Ultra-violet laser ablation has also been used to form patterns etc on circuit boards. However, the short absorption depth of the UV radiation from pulsed UV lasers limits the ablation depth of metal films to less than 400 nm per exposure. The pulse repetition frequency of these lasers is also relatively low. These effects limit the processing speed with these lasers and although it is possible to pattern metal films, drill through holes and cut, the speed of processing is slow. The UV radiation is strongly absorbed by both the conductor layer and the insulating substrate, so the exposure and initial film thickness must be carefully controlled if one layer is to be completely ablated without damaging the other.

Electron and ion beam processing have also been used but require high vacuum environments which limits the practicality and application of these techniques. Again, there is little differential processing of the different layers so exposure and film thickness must be carefully

controlled if one layer is to be removed without damaging the other layer.

There have also been proposals to drill through holes in circuit boards using two lasers. A ruby or eximer laser is used to drill through the metal layer and a CO_2 or Nd:YAG laser is used to drill through a polymeric substrate. Short, high energy laser pulses are used to vapourise the material in the shortest possible time while causing the least amount of damage to the areas immediately surrounding the hole. This technique appears to be limited to the drilling of holes due to the low pulse repetition rate of ruby and eximer lasers and is relatively expensive as two separate lasers are required to drill the different layers.

The present invention aims to provide a method and apparatus for selective machining of components such as circuit boards which improve upon the prior art techniques referred to above.

According to a first aspect of the present invention there is provided a method of selectively machining a component comprising a first and a second material, the method comprising the steps of:

using a single laser having at least a first and a second emission wavelength;

selectively irradiating the component with a pulsed laser beam of said first wavelength at an energy fluence sufficient to cause ablation of the first material but insufficient to cause appreciable ablation of the second material; and

selectively irradiating the component with a pulsed laser beam of said second wavelength at an energy fluence sufficient to cause ablation of at least the second material.

According to another aspect of the invention, there is provided apparatus for selectively machining a component comprising a first material and a second material, the apparatus comprising:

a single laser having at least two emission wavelengths; and

control means for selectively directing a pulsed laser beam of said first wavelength at the component at an energy fluence sufficient to ablate portions thereof comprising the first material but insufficient to cause appreciable ablation of the second material and for directing a pulsed laser beam of said second wavelength at the component at an energy fluence sufficient to ablate at least portions thereof comprising the second material.

Other features of the invention will be apparent from the following description and from the subsidiary claims of the specification.

The invention will now be further described, merely by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a schematic diagram illustrating the use of apparatus according to the invention being used to selectively machine the layers of a circuit board; and

Figure 2 is a graph showing the wavelength absorption charateristics of materials commonly used in a circuit board.

A wide variety of lasers have existed since the 1960s and 1970s including: ruby lasers, excimer lasers, Nd:YAG lasers, CO_2 lasers, copper lasers and dye lasers. As mentioned above, it has been proposed to use two separate lasers, such as a ruby laser and a CO_2 laser either simultaneously or in succession to drill a hole through a circuit board comprising a layer of copper on a polymer substrate. However, it would appear that no-one has considered the possibility of extending this idea further by using a single laser having at least two emission wavelengths to selectively machine tracks and to form cuts, as

well as holes, on a circuit board, the laser being selected such that one of its emission wavelengths, at a given energy fluence, will ablate the copper layer but not cause appreciable ablation of the insulating substrate so this wavelength can be used to machine tracks in the copper layer without damaging the underlying substrate, whereas the second emission wavelength at a given energy fluence can be used to ablate at least the insulating substrate.

Figure 1 illustrates apparatus which comprises a single laser 1 having two emission wavelengths which show differential machining of layers 2, 3 of a circuit board when used at the appropriate energy fluences and thus permits the selective removal of at least one of these layers. The upper layer 2 is typically a layer of copper 0 to 300μm thick and the lower layer 3 is typically of insulating material between 10μm and 10mm thick.

The circuit board is mounted on a pair of orthogonal translation tables 4 so that it can be moved in the x and y directions as shown, relative to the laser beam. A wavelength selecting device 5 is used to select the wavelength used to irradiate the circuit board. In some cases, it may be advantageous to locate the wavelength selecting device inside the laser cavity 1. A lens 6 is preferably used to focus the laser beam to a small spot on the area of the circuit board which is to be ablated.

The apparatus shown in Figure 1 may be used to cut patterns in the copper layer 2 by irradiating the copper layer at one wavelength at the appropriate energy fluence such that the copper is ablated without damaging the underlying insulating substrate and by moving the circuit board relative to the laser beam so that the required portions of the copper layer are removed.

The apparatus may similarly be used to cut holes and slots through the board by irradiating the circuit board with the other wavelength at an energy fluence which is sufficient to ablate the insulating layer 3. This may be achieved by first ablating the copper layer 2 with the first wavelenth and then ablating the exposed insulating layer 3 with

the second wavelength. Alternatively, the two wavelengths may be used simultaneously to ablate the two layers.

In many cases, the second wavelength will ablate the copper layer 2 as well as the insulating layer 3. However, this is of no consequence if the second wavelength is used to form through-holes and cuts in the circuit board. If it is desired to ablate the insulating layer 3 without damaging the copper layer 2, it is necessary to use a laser which emits a wavelength which, at a given energy fluence, would ablate the insulating material without ablating the copper.

It will also be appreciated that if the second material is sufficiently transparent to the first wavelengh, a layer of the first material may be ablated by a beam transmitted through a layer of the second material, eg a coppper layer on the underside of an insulating layer may be ablated by a laser beam passing through the insulating layer.

Holes may thus be cut through the circuit board by using the two different wavelengths (either simultaneously or successively) and, by moving the circuit board relative to the laser beam during this process, a slot can be cut through the board, eg. to cut a relatively large hole in the board or to cut an individual board from a larger sheet of material.

As will be discussed further below, the wavelength, energy fluence, intensity, pulse length and pulse repetition frequency of the respective wavelengths may be adjusted to optimise the process.

The laser beam is either focussed or imaged to a small spot. The spot may be moved relative to the workplace either by scanning or deflecting the beam or moving the work piece (as indicated above), or both. The movement may be directly controlled from a computer or some other other controlling device. In this way the pattern, holes and cuts are produced directly without the need for artwork or photographic reduction. This reduces the set-up time and costs and also reduces the potential for errors. The fundamental resolution of

this technique is only limited by the final laser spot size which can be very small. In addition, there is no fundamental limit to the area over which this resolution may be achieved.

By employing multiple workpieces and laser beams, it is also possible to simultaneously produce a large number of identical finished components.

As discussed above, the laser 1 is of a type which produces more than one laser emission wavelength and these wavelengths may be rapidly switched or combined so as to selectively etch or through drill and cut. The laser 1 may be a broadband laser from which various laser emission wavelengths are either selected simultaneously or sequentially. Alternatively, the laser may emit at a plurality of discrete wavelengths or bands, either simultaneously or sequentially. The laser medium may be a single laser material type or some mixture of different laser material types, each producing a different wavelength. Examples of lasers that are capable of emitting at different wavelengths are: metal vapour lasers, dye lasers, laser diodes, neodynium ion solid state lasers, tunable solid state lasers such as Ti:sapphire, alexandrite, Cr:LiSAF and Cr:LiCAF and various gas lasers.

The two wavelengths may be split, selected or combined with suitable wavelength selection means such as dichroic mirrors, prisms, gratings, etalons, birefringent elements, absorbent materials or other devices.

The laser 1 preferably has the following properties: it is pulsed with a short pulse duration (< 1 μs duration), low pulse energy (<100 mJ), very high pulse repetition frequency (>1kHz), and good beam quality (<10 times the diffraction limit). The laser emission wavelengths used are preferably less than 3μm as these short wavelengths generally ablate metals more efficiently than longer wavelengths.

The short pulse from the laser heats only the target area and does not allow time for the heat to diffuse into the surrounding material thereby avoiding a large heat affected zone. The low pulse energy of the laser prevents large amounts of material being removed with each pulse and

hence widening the hole, cut or area ablated. The high repetition rate allows a significant cutting speed to be acheived despite the low amount of material removed with each pulse. The good beam quality allows the beam to achieve a small spot for high resolution ablating, drilling and cutting. A laser having the above properties enables ablating, drilling and cutting of metal - insulator multilayer sheets or objects in a single process with high accuracy over large areas and with short set-up times.

Advantageously, the laser 1 is a copper vapour laser (CVL) as this has the required properties. The copper vapour laser has two simultaneous wavelengths (511nm and 578nm). The insulating layer 3 is largely transparent to the 578 nm wavelength but this wavelength is absorbed sufficiently by the copper layer so, with the appropriate energy fluence, enabling the selective removal of the copper layer from the insulating layer. By using both wavelengths, it is possible to drill through holes and make cuts in the circuit board.

As discussed above, it is known to drill holes through a circuit board using two separate lasers which are used to vaporise the two types of material forming the layers of the circuit board. One reason why this idea has not previously been extended to the use of a single laser to selectively ablate one layer to form tracks etc as described above is that it may have been thought that this was not possible with a single laser as a single type of laser would not be capable of generating the wavelengths having the required different machining properties. In general, pulsed lasers that are capable of emitting two or more wavelengths do so over only a relatively narrow wavelength band, eg. of only 50nm or so. It may have been assumed that such a small wavelength difference was not sufficient to provide the required difference in ablation of the two types of material used in the manufacture of components such as circuit boards.

However, investigations into the absorption characteristics of the relevant materials have surprisingly shown that this small difference in wavelength is sufficient. Figure 2 illustrates the absorption

characteristic of a polyimide material sold under the trade name Kapton having a thickness of around 50µm. As shown, these investigations revealed that the slope of the transmission curve for Kapton is relatively steep for wavelengths in the region of the copper vapour laser wavelengths and relatively flat on either side of these wavelengths. As shown in Figure 2, the wavelength of 578nm is largely transmitted by Kapton (only approximately 50% being absorbed) whereas the 511 nm wavelength is largely absorbed (approximately 92%) by this material.

Figure 2 also shows the absorption characteristic for a copper layer. About 15% of the 578nm wavelength is absorbed by the copper layer. However, with an appropriate energy fluence, this is sufficient to cause ablation of a relatively thin copper layer. The important feature to note is that due to the relatively low absorption of this wavelength by the Kapton layer it is possible to selectively ablate the copper layer without damaging the underlying Kapton layer. The 511nm wavelength is approximately 40% absorbed by the copper layer. This helps form a hole through the circuit board when this wavelength is used to ablate the Kapton layer or is of no consequence if the copper layer has already been removed.

It will also be noted from Figure 2 that the absorption % for copper becomes much lower for higher wavelengths such as those emitted by ruby, Nd:YAG and CO_2 lasers (694nm, 1064nm and 10600nm, respectively). As mentioned above, it has been found that 15% absorption is sufficient to enable the copper layer to be ablated without the need to use high energy pulses (which would increase the risk of damaging the underlying insulating layer).

Thus, by appropriate matching of the laser wavelengths and energy fluences with the absorption/transmission characteristics of the respective materials, in this case a copper vapour laser with emissions at 511 and 578 nm and a circuit board comprising a thin layer of copper (eg <5µm thick) on a Kapton substrate, it is possible to provide

apparatus comprising a single laser which is capable of selectively ablating the respective materials.

This example relates specifically to the copper vapour laser and a circuit board fabricated from copper and Kapton but having appreciated that such an arrangement is possible, other similar arrangements using other lasers and other materials will occur to those skilled in the art. A gold vapour laser may, for instance, be used as it has two emission wavelengths of 312nm and 628nm, respectively. The 628nm wavelength could be used to ablate the copper layer as Kapton absorbs less than 50% of this wavelength whilst the 312nm wavelength could be used to ablate the Kapton.

As mentioned above the machining process may be further controlled by controlling other parameters of the laser beam as, irrespective of the degree of absorption, there is a minimum energy fluence or intensity for each material which is required to cause ablation. With a higher degree of absorption, the lower the energy required and vice versa.

A pulse repetition frequency of at least 1000Hz is preferable although higher or lower frequencies may be used. It will be appreciated that the higher the pulse repetition frequency, the faster the material will be ablated. With relatively low energy pulses, it is desirable to use a relatively high repetition frequency to enable oblation to occur at a reasonable rate.

The pulse width should preferably be less than 1 μsec to ensure efficient ablation of material without significantly affecting the surrounding area.

The pulse fluence, ie the energy input per pulse divided by the area of the laser spot incident on the material, should preferably be less than $500J/cm^2$ and most preferably in the range $10\text{-}100J/cm^2$. The intensity of the laser beam should also preferably be less than 10 GW/cm^2. This relatively low energy fluence and intensity reduces the

amount of material ablated by each pulse (so minimising the damage to the surrounding area) but combined with the high pulse repetition frequency referred to above enables an appreciable amount of material to be ablated within a reasonable time.

As an example, a copper layer of 0.6μm thickness may be ablated by a single pulse having an energy fluence of 20J/cm^2, and a pulse duration of 50ns. A thicker layer would require a correspondingly larger number of pulses, eg a copper layer 300 μm thick would be ablated by around 200 pulses at a fluence of 500J/cm^2 which, at a pulse repetition rate of 10,000Hz, would be delivered within 0.02 secs.

The diameter of the spot incident on the component would typically be in the range 1μm to 250μm.

The apparatus would usually be operated so that the integrated energy fluence incident at a given point on the workpiece remains substantially constant. This means, for example, that the pulse repetition rate is increased as the speed of movement of the laser beam relative to the workpiece is increased and vice versa. The pulse energy may also be increased as the spot size increases.

The method described above enables the fabrication of high resolution, flexible circuits and detectors, eg detectors of ionising radiation used in nuclear physics. Beginning with a sheet of polyimide with a continuous layer of copper on one side of the sheet, the 578 nm line of the copper vapour laser is used to create a pattern of copper tracks and pads for the circuit by selectively ablating the copper where it is not required. Because of the small laser spot size and lack of a heat affected zone, the width of the copper tracks can be chosen to be any width; the minimum practical width being 1 μm. The area over which the circuit extends is only limited by the travel of the translation stages which carry the work piece or the range of deflection of the beam. Thus the area can be as large as several square meters. The copper around the edge of the circuit area can also be ablated to leave an area of polyimide around the circuit. The combination of the 511

drill through-holes through the pads. The 511 nm wavelength can then be used to cut through the polyimide around the edge of the circuit thereby completing fabrication of the circuit board from the sheet.

The apparatus described above thus enables the patterning, drilling and cutting of metal - plastic multilayer films or objects by use of a single laser which can generate a plurality of laser emission wavelengths in short pulses of low energy at high pulse repetition rates. In particular, it enables the removal of the metal film in selected areas from a metal - plastics multilayer sheet or object without damaging the plastics substrate using a copper vapour laser. It also enables through drilling and cutting of the complete multilayer sheet or object. Unlike the prior art, the method described enables all these steps to carried out at the same station using a single laser. There is therefore no need to first etch a pattern in the copper layer at one station, move to another station for drilling through holes in the board and then to a third station to cut excess border material from the board.

CLAIMS

1. A method of selectively machining a component comprising a first and a second material, the method comprising the steps of:

   using a single laser having at least a first and a second emission wavelength;

   selectively irradiating the component with a pulsed laser beam of said first wavelength at an energy fluence sufficient to cause ablation of the first material but insufficient to cause appreciable ablation of the second material; and

   selectively irradiating the component with a pulsed laser beam of said second wavelength at an energy fluence sufficient to cause ablation of at least the second material.

2. A method as claimed in claim 1 in which the component is a circuit board, the first material being a metal layer, eg copper, and the second material being an insulating substrate, eg of polyimide.

3. A method as claimed in claim 2 in which the areas of the metal layer are selectively ablated to form electrical tracks on the circuit board.

4. A method as claimed in claim 2 or 3 in which the first and second wavelengths are used, simultaneously or successively, to form holes or slots in the circuit board.

5. A method as claimed in claim 3 or 4 in which the circuit board is moved relative to the laser beam or vice versa.

6. A method as claimed in any preceding claim in which the laser is a copper vapour laser.

7. A method as claimed in any preceding claim in which the pulse repetition frequency of the laser is at least 1000Hz

8. A method as claimed in any preceding claim in which the duration of each pulse is 1 μsec or less.

9. A method as claimed in any preceding claim in whcih the pulse fluence incident on the component is 500J/cm² or less.

10. A method as claimed in any preceding claim in which the laser spot incident on the component has a diameter within the size 1μm to 250μm.

11. A method of selectively machining a component comprising a first material and a second material substantially as hereinbefore described.

12. Apparatus for selectively machining a component comprising a first material and a second material, the apparatus comprising:

a single laser having at least two emission wavelengths;

and control means for selectively directing a pulsed laser beam of said first wavelength at the component at an energy fluence sufficient to ablate portions thereof comprising the first material but insufficient to cause appreciable ablation of the second material and for directing a pulsed laser beam of said second wavelength at the component at an energy fluence sufficient to ablate at least portions thereof comprising the second material.

13. Apparatus as claimed in claim 12 in which the control means comprises wavelength selector means.

14. Apparatus as claimed in claim 12 or 13 in which the control means comprises means for varying one or more of the following laser parameters: the pulse repitition frequency, the pulse duration,

the pulse fluence, the pulse intensity and the spot size incident on the component.

15. Apparatus as claimed in claim 12, 13 or 14 which comprises means for moving the component relative to the laser beam or vice versa.

16. Apparatus as claimed in claim 15 in which the means for moving the component comprises one or more translation tables.

17. Apparatus as claimed in claim 15 or 16 in which the means for moving the component comprises deflecting means for deflecting the laser beam.

18. Apparatus as claimed in any of claims 15 to 17 in which the control means comprises computer control means for controlling movement of the laser beam relative to the component.

19. Apparatus as claimed in any of the claims 12 to 18 in which the laser is a copper vapour laser.

20. Apparatus for selectively machining a component comprising a first material and a second material substantially as hereinbefore described with reference to the accompanying drawings.

Patents Act 1977 Examiner's report to the C mptroller under Section 17 (The Search report)	Application number GB 9403733.0
Relevant Technical Fields (i) UK Cl (Ed.N) B3V (ii) Int Cl (Ed.6) B23K **Databases (see below)** (i) UK Patent Office collections of GB, EP, WO and US patent specifications. (ii)	Search Examiner D N P BUTTERS Date of completion of Search 4 MAY 1995 Documents considered relevant following a search in respect of Claims :- 1-20

Categories of documents

X: Document indicating lack of novelty or of inventive step.

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A: Document indicating technological background and/or state of the art.

P: Document published on or after the declared priority date but before the filing date of the present application.

E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

&: Member of the same patent family; corresponding document.

Category	Identity of document and relevant passages	Relevant to claim(s)
A	GB 1326775 (APPLIED DISPLAY)	
A	EP 0544398 (BRITISH AEROSPACE)	

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